15. How much heat is needed to change 3.00×10^2 g of ice at –30.0°C to steam at 130.0°C?

Warm ice from –30°C to 0°C:
$Q = mC\Delta T$ = (0.300 kg)(2060 J/kg·C°)(30.0°C) = 0.185×10^5 J

Melt ice:
$Q = mH_f$ = (0.300 kg)(3.34×10^5 J/kg) = 1.00×10^5 J

Heat water 0°C to 100°C:
$Q = mC\Delta T$ =(0.300 kg)(4180 J/kg·C°)(100°C) = 1.25×10^5 J

Vaporize water:
$Q = mH_v$ = (0.300 kg)(2.26×10^6 J/kg) = 6.78×10^5 J

Heat steam 100°C to 130°C:
$Q = mC\Delta T$ = (0.300 kg)(2020 J/kg·C°)(30°C) = 0.18×10^5 J
$Q_{total} = 9.40 \times 10^5$ J

16. A 175–g lump of molten lead at its melting point, 327°C, is dropped into 55 g of water at 20.0°C.

a. What is the temperature of the water when the lead becomes solid?

To freeze, lead must absorb
$Q = -mH_f = -(0.175 \text{ kg})(2.04 \times 10^4 \text{ J/kg}) = -3.57 \times 10^3$ J

This will heat the water, $$\Delta T = \frac{Q}{mC} = \frac{(3.57 \times 10^3 \text{ J})}{(0.055 \text{ kg})(4180 \text{ J/kg}\cdot\text{K})} = 16°\text{C to } 36°\text{C}$$

b. When the lead and water are in thermal equilibrium, what is the temperature?

Now, $$T_f = \frac{(m_A C_A T_{Ai} + m_B C_B T_{Bi})}{(m_A C_A + m_B C_B)}$$
$$= \frac{(0.175 \text{ kg})(130 \text{ J/kg}\cdot\text{K})(327°\text{C}) + (0.55 \text{ kg})(4180 \text{ J/kg}\cdot\text{K})(35.5°\text{C})}{(0.175 \text{ kg})(130 \text{ J/kg}\cdot\text{K}) + (0.055 \text{ kg})(4180 \text{ J/kg}\cdot\text{K})} = 62°\text{C}$$

Chapter Review Problems

pages 262–263

1. Liquid nitrogen boils at 77°K. Find this temperature in degrees Celsius.

°C = K – 273 = 77 – 273 = –196°C

2. The melting point of hydrogen is –295.14°C. Find this temperature in kelvin.

K = °C + 273.15 = –259.14 + 273.15
= 14.01 K

3. Sadi Carnot showed that no real heat engine can have an efficiency greater than

$$Efficiency = \frac{Work\ output}{Heat\ input} = \frac{T_{hot} - T_{cold}}{T_{hot}}$$

where T_{hot} and T_{cold} are the temperatures of the input and waste thermal energy. Note: kelvin temperatures must be used in this equation.

a. What is the efficiency of an ideal steam engine that uses superheated steam at 685 K to drive the engine and ejects waste steam at 298 K?

$$Efficiency = \frac{T_{hot} - T_{cold}}{T_{hot}} = \frac{685\ K - 298\ K}{685\ K} = 0.565$$

b. If the steam generator produces 1.00×10^8 J each second, how much work can the ideal engine do each second?

Work output = (*efficiency*)(*heat input*) = 5.65×10^7 J/s.

4. How much heat is needed to raise the temperature of 50.0 g of water from 4.5°C to 83.0°C?

$Q = mC\Delta T = (0.0500\ kg)(4180\ J/kg \cdot K)(83.0 - 4.5) = 1.6 \times 10^4\ J$

5. How much heat must be added to 50.0 g of aluminum at 25°C to raise its temperature to 125°C?

$Q = mC\Delta T = (0.0500\ kg)(903\ J/kg \cdot K)(125°C - 25°C) = 4.5 \times 10^3\ J$

6. A 5.00×10^2-g block of metal absorbs 5016 J of heat when its temperature changes from 20.0°C to 30.0°C. Calculate the specific heat of the metal.

$$Q = mC\Delta T, \text{ so } C = \frac{Q}{m\Delta T} = \frac{5016\ J}{(5.00 \times 10^{-1}\ kg)(30.0°C - 20.0°C)} = 1.00 \times 10^3\ J/kg\ K$$

7. A 4.00×10^2-g glass coffee cup is at room temperature, 20.0°C. It is then plunged into hot dishwater, 80.0°C. If the temperaure of the cup reaches that of the dishwater, how much heat does the cup absorb? Assume the mass of the dishwater is large enough so its temperature doesn't change appreciably.

$Q = mC\Delta T = (4.00 \times 10^{-1}\ kg)(664\ J/kg \cdot K)(80.0°C - 20.0°C) = 1.59 \times 10^4\ J$

8. A copper wire has a mass of 165 g. An electric current runs through the wire for a short time and its temperature rises from 21°C to 39°C. What minimum quantity of energy is converted by the electric current?

$Q = mC\Delta T = (0.165\ kg)(385\ J/kg \cdot K)(39°C - 21°C) = 1.1 \times 10^3\ J$

9. A 1.00×10^2-g mass of tungsten at 100.0°C is placed in 2.00×10^2 g of water at 20.0°C. The mixture reaches equilibrium at 21.6°C. Calculate the specific heat of tungsten.

$\Delta E_t + \Delta E_w = 0$, or $m_t C_t \Delta T_t = -m_w C_w \Delta T_w$, so

$$C_t = \frac{-m_w C_w \Delta T_w}{m_t \Delta T_t} = \frac{-(0.200\ kg)(4180\ J/kg \cdot K)(21.6°C - 20.0°C)}{(0.100\ kg)(21.6°C - 100.0°C)} = 171\ J/kg \cdot K$$

10. A 6.0×10^2–g sample of water at 90.0°C is mixed with 4.00×10^2 g of water at 22°C. Assume no heat loss to the surroundings. What is the final temperature of the mixture?

$$T_f = \frac{m_A C_A T_{Ai} + m_B C_B T_{Bi}}{m_A C_A + m_B C_B}$$ but $C_A = C_B$, because both liquids are water and C_A's will divide out.

$$T_f = \frac{m_A T_{Ai} + m_B T_{Bi}}{m_A + m_B} = \frac{(6.0 \times 10^2\ \text{g})(90.0°\text{C}) + (4.00 \times 10^2\ \text{g})(22°\text{C})}{6.0 \times 10^2\ \text{g} + 4.0 \times 10^2\ \text{g}} = 63°\text{C}$$

11. To get a feeling for the amount of energy needed to heat water, recall from Table 11–1 that the kinetic energy of a compact car moving at 100 km/h is 2.9×10^5 J. What volume of water (in liters) would 2.9×10^5 J of energy warm from room temperature (20°C) to boiling (100°C)?

$$Q = mC\Delta T, \text{ so } m = \frac{Q}{C\Delta T} = \frac{(2.9 \times 10^5\ \text{J})}{(4180\ \text{J/kg}\cdot\text{K})(100°\text{C} - 20°\text{C})} = 0.87\ \text{kg} = 0.87\ \text{L}$$

12. A 10.0–kg piece of zinc at 71°C is placed in a container of water. The water has a mass of 20.0 kg and has a temperature of 10.0°C before the zinc is added. What is the final temperature of the water and zinc?

$$T_f = \frac{m_{Zn} C_{Zn} T_{Zni} + m_w C_w T_{wi}}{m_{Zn} C_{Zn} + m_w C_w} = \frac{(10.0\ \text{kg})(388\ \text{J/kg}\cdot\text{K})(71°\text{C}) + (20.0\ \text{kg})(4180\ \text{J/kg}\cdot\text{K})(10.0°\text{C})}{(10.0\ \text{kg})(388\ \text{J/kg}\cdot\text{K}) + (20.0\ \text{kg})(4180\ \text{J/kg}\cdot\text{K})} = 12.7°\text{C}$$

13. A 2.00×10^2–g sample of brass at 100.0°C is placed in a calorimeter cup that contains 261 g of water at 20.0°C. Disregard the absorption of heat by the cup and calculate the final temperature of the brass and water.

$$T_f = \frac{m_w C_w T_{wi} + m_B C_B T_{Bi}}{m_w C_w + m_B C_B} = \frac{(0.261\ \text{g})(4180\ \text{J/kg}\cdot\text{K})(20.0°\text{C}) + (0.200\ \text{kg})(376\ \text{J/kg}\cdot\text{K})(100.0°\text{C})}{(0.261\ \text{g})(4180\ \text{J/kg}\cdot\text{K}) + (0.200\ \text{kg})(376\ \text{J/kg}\cdot\text{K})}$$
$$= 25.1°\text{C}$$

14. A 3.00×10^2–W electric immersion heater is used to heat a cup of water. The cup is made of glass and its mass is 3.00×10^2 g. It contains 250 g of water at 15°C. How much time is needed for the heater to bring the water to the boiling point? Assume the temperature of the cup to be the same as the temperature of the water at all times and no heat is lost to the air.

$Q = m_g C_g \Delta T_g + m_w C_w \Delta T_w$, but $\Delta T_g = \Delta T_w$, so
$Q = [m_g C_g + m_w C_w]\Delta T = [(0.300\ \text{kg})(664\ \text{J/kg}\cdot\text{K}) + (0.250\ \text{kg})(4180\ \text{J/kg}\cdot\text{K})](100°\text{C} - 15°\text{C})$
$= 1.1 \times 10^5$ J.

Now $P = \frac{E}{t}$ or $P = \frac{Q}{t}$, so $t = \frac{Q}{P} = \frac{1.1 \times 10^5\ \text{J}}{3.00 \times 10^2\ W} = 3.7 \times 10^2$ s

15. A 2.50×10^2–kg cast–iron car engine contains water as a coolant. Suppose the engine's temperature is 35°C when it is shut off. The air temperature is 10°C. The heat given off by the engine and water in it as they cool to air temperature is 4.4×10^6 J. What mass of water is used to cool the engine?

$Q = m_w C_w \Delta T + m_i C_i \Delta T$

$$m = \frac{Q - m_i C_i \Delta T}{C_w \Delta T} = \frac{(4.4 \times 10^6\ \text{J}) - [(2.50 \times 10^2\ \text{kg})(450\ \text{J/kg}\cdot\text{C°})(35°\text{C} - 10°\text{C})]}{(4180\ \text{J/kg}\cdot\text{C°})(35°\text{C} - 10°\text{C})} = 15\ \text{kg}$$

16. Years ago, a block of ice with a mass of about 20.0 kg was used daily in a home icebox. The temperature of the ice was 0.0°C when delivered. As it melted, how much heat did a block of ice that size absorb?

$Q = mH_f = (20.0\ \text{kg})(3.34 \times 10^5\text{J/kg}) = 6.68 \times 10^6$ J

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17. A person who eats 2400 food calories each day consumes 1.0×10^7 joules of energy in a day. How much water at 100°C could that much energy vaporize?

$$Q = mH_v, \text{ so } m = \frac{Q}{H_v} = \frac{1.0 \times 10^7 \text{ J}}{2.26 \times 10^6 \text{ J/kg}} = 4.4 \text{ kg}$$

18. A 40.0-g sample of chloroform is condensed from a vapor at 61.6°C to a liquid at 61.6°C. It liberates 9870 joules of heat. What is the heat of vaporization of chloroform?

$$Q = mH_v$$

$$H_v = \frac{Q}{m} = \frac{9870 \text{ J}}{0.0400 \text{ kg}} = 247 \times 10^5 \text{ J/kg}$$

19. How much heat is removed from 60.0 g of steam at 100.0°C to change it to 60.0 g of water at 20.0°C?

The amount of heat liberated when the steam condenses is
$Q = -mH_v$ (negative for condensation) $= -(0.0600 \text{ kg})(2.26 \times 10^6 \text{ J/kg}) = -1.36 \times 10^5$ J.

The amount of heat liberated as the water cools to 20.0°C is
$Q = mC\Delta T = (0.0600 \text{ kg})(4180 \text{ J/kg}\cdot\text{K})(20.0°\text{C} - 100.0°\text{C}) = -2.01 \times 10^4$ J.

The total heat is $(-1.36 \times 10^5 \text{ J}) + (-2.01 \times 10^4 \text{ J}) = 1.56 \times 10^5$ J.

20. A 750-kg car moving at 23 m/s brakes to a stop. The brakes contain about 15 kg of iron that absorb the energy. What is the increase in temperature of the brakes?

During braking, the kinetic energy of the car is converted into heat energy. So $\Delta KE_C + Q_B = 0$ and $\Delta KE_C + m_B C_B \Delta T = 0$ so

$$\Delta T = \frac{-\Delta KE_C}{m_B C_B} = \frac{\frac{1}{2}m_C(v_f^2 - v_i^2)}{m_B C_B} = \frac{-\frac{1}{2}(750 \text{ kg})(0^2 - (23 \text{ m/s})^2)}{(15 \text{ kg})(450 \text{ J/kg}\cdot\text{K})} = 29°\text{C}$$

21. How much heat is added to 10.0 g of ice at -20.0°C to convert it to steam at 120.0°C?

Amount of heat needed to heat ice to 0.0°C,
$Q = mC\Delta T = ((0.0100 \text{ kg})(2060 \text{ J/kg}\cdot°\text{C})(0.0°\text{C} - (-20.0°\text{C}) = 412$ J.

Amount of heat to melt ice,
$Q = mH_f = ((0.0100 \text{ kg})(3.34 \times 10^5 \text{ J/kg}) = 3.34 \times 10^3$ J.

Amount of heat to heat water to 100.0°C,
$Q = mC\Delta T = (0.0100 \text{ kg})(4180 \text{ J/kg}\cdot°\text{C})(100.0°\text{C} - 0.0°\text{C}) = 4.18 \times 10^3$ J.

Amount of heat to boil water,
$Q = mH_v = (0.0100 \text{ kg})(2.26 \times 10^6 \text{ J/kg}) = 2.26 \times 10^4$ J.

Amount of heat to heat steam to 120.0°C,
$Q = mC\Delta T = (0.0100)(2020 \text{ J/kg}\cdot°\text{C})(120.0°\text{C} - 100.0°\text{C}) = 404$ J.

The total heat is $412 \text{ J} + 3.34 \times 10^3 \text{ J} + 4.18 \times 10^3 \text{ J} + 2.26 \times 10^4 \text{ J} + 404 \text{ J} = 3.09 \times 10^4$ J

22. A 50.0-g sample of ice at 0.00°C is placed in a glass beaker containing 4.00×10^2 g of water at 50.0°C. All the ice melts. What is the final temperature of the mixture? Disregard any heat loss to the glass.

$Q_i + Q_w = 0$, so
$[m_i H_f + m_i C\Delta T\,] + m_w C\Delta T_w$
or $(0.0500 \text{ kg})(3.34 \times 10^5 \text{ J/kg}) + (0.0500 \text{ kg})(4180 \text{ J/kg°C})(T_f - 0.0°\text{C})$
$+ (0.400 \text{ kg})(4180 \text{ J/kg°C})(T_f - 50.0°\text{C}) = 0$ or
$1.67 \times 10^4 \text{ J} + (209 \text{ J})T_f - 0.0 + (1.67 \times 10^3 \text{ J})T_f - 8.36 \times 10^4 \text{ J} = 0$
or $(1.88 \times 10^3 \text{ J})T_f = 6.69 \times 10^4 \text{ J}$ or $T_f = 35.6°\text{C}$.

23. A 4.2-g lead bullet moving at 275 m/s strikes a steel plate and stops. If all its kinetic energy is converted to thermal energy and none leaves the bullet, what is its temperature change?

Because the kinetic energy is converted to thermal energy, $\Delta KE + Q = 0$. So
$\Delta KE + m_B C_B \Delta T$ and

$$\Delta T = \frac{\Delta KE}{m_B C_B} = \frac{\frac{1}{2} m_B (v_f^{\,2} - v_i^2)}{m_B C_B}$$

and the mass of the bullet divides out so

$$\Delta T = \frac{\frac{1}{2}(v_f^2 - v_i^2)}{C_B} = \frac{\frac{1}{2}(0^2 - (275 \text{ m/s})^2)}{130 \text{ J/kg} \cdot °\text{C}}$$
$= 291°\text{C}$.

24. A soft drink from Australia is labeled "Low Joule Cola". The label says "100 mL yields 1.7 kJ". The can contains 375 mL. Sally drinks the cola and then offsets this input of food energy by climbing stairs. How high would she have to climb if Sally has a mass of 65.0 kg?

Sally gained $(3.75)(1.7 \text{ kJ}) = 6.4 \times 10^3$ J of energy from the drink. To conserve energy $E + \Delta PE = 0$ or $6.4 \times 10^3 \text{ J} = -mg\Delta h$ so,

$$\Delta h = \frac{6.4 \times 10^3 \text{ J}}{-mg} = \frac{6.4 \times 10^3 \text{ J}}{-(65.0 \text{ kg})(-9.80 \text{ m/s}^2)} = 10 \text{ m, or about three flights of stairs.}$$

25. When air is compressed in a bicycle pump, an average force of 45 N is exerted as the pump handle moves 0.24 m. During this time 2.0 J of heat leave the cylinder through the walls. What is the net change in thermal energy of the air in the cylinder?

Change in thermal energy = heat added + work done = $-2.0 \text{ J} + (45 \text{ N})(0.24 \text{ m}) = 8.8 \text{ J}$.

Supplemental Problems (Appendix B)

1. The boiling point of liquid chlorine is −34.60°C. Find this temperature in Kelvin.

K = °C + 273.15 = −34.60 + 273.15 = 238.55 K

2. Fluorine has a melting point of 50.28 K. Find this temperature in degrees Celsius.

°C = K − 273.15 = 50.28 − 273.15 = −222.87°C

3. Five kilograms of ice cubes are moved from the freezing compartment of a refrigerator into a home freezer. The refrigerator's freezing compartment is kept at –4.0°C. The home freezer is kept at –17°C. How much heat does the freezer's cooling system remove from the ice cubes?

$Q = mC\Delta T = (5.0 \text{ kg})(2060 \text{ J/kg}\cdot\text{K})(-4.0°\text{C} - (-17°\text{C})) = 1.3 \times 10^5 \text{ J removed}$

4. How much heat must be added to 124 g of brass at 12.5°C to raise its temperature to 97.0°C?

$Q = m_C\Delta T = (0.124 \text{ kg})(376 \text{ J/kg}\cdot\text{C°})(84.5°\text{C}) = 3.94 \times 10^3 \text{ J}$

5. 2.8×10^5 J of thermal energy are added to a sample of water and its temperature changes from 293 K to 308 K. What is the mass of water?

$$M = \frac{Q}{C\Delta T} = \frac{2.8 \times 10^5 \text{ J}}{(4180 \text{ J/kg}\cdot\text{C°})(15°\text{C})} = 4.5 \text{ kg}$$

6. 1420 J of thermal energy are added to a 100.0–g block of carbon at –20.0°C. What final temperature will the carbon reach?

$$\Delta T = \frac{Q}{mC} = \frac{1420 \text{ J}}{(710 \text{ J/kg}\cdot\text{C°})(0.100 \text{ kg})} = 20.0°\text{C}.$$

Final temperature is –20°C + 20°C = 0°C

7. A gold brick of mass 10.5 kg requires 2.08×10^4 J of heat to change its temperature from 35.0°C to 50.0°C. What is the specific heat of gold?

$$C = \frac{Q}{m\Delta T} = \frac{2.08 \times 10^4 \text{ J}}{(10.5 \text{ kg})(15.0°\text{C})} = 132 \text{ J/kg}\cdot\text{K}$$

8. An 8.00×10^2–g block of lead is heated in boiling water, 100.0°C, until the block's temperature is the same as the water's. The lead is then removed from the boiling water and dropped into 2.50×10^2 g of cool water at 12.2°C. After a short time, the temperature of both lead and water is 20.0°C.

a. How much heat is gained by the cool water?

$Q = mC\Delta T = (2.50 \times 10^{-1} \text{ kg})(4180 \text{ J/kg}\cdot\text{K})(20.0°\text{C} - 12.2°\text{C}) = 8.2 \times 10^3 \text{ J}$

b. On the basis of these measurements, what is the specific heat of lead?

$$C_{lead} = \frac{Q}{m\Delta T} = \frac{-8.2 \times 10^3 \text{ J}}{(8.00 \times 10^{-1} \text{ kg})(20.0°\text{C} - 100.0°\text{C})} = 1.3 \times 10^2 \text{ J/kg}\cdot\text{K}$$

9. 250.0 g of copper at 100.0°C are placed in a cup containing 325.0 g of water at 20.0°C. Assume no heat loss to the surroundings. What is the final temperature of the copper and water?

Copper Water

$$Q_{loss} = Q_{gain}$$
$$(0.250 \text{ kg})(385 \text{ J/kg}\cdot\text{C°})(100.0°\text{C} - T_f) = (0.325 \text{ kg})(4180 \text{ J/kg}\cdot\text{C°})(T_f - 20.0°\text{C})$$
$$9.63 \times 10^3 - 9.63 \times 10^1\ T_f = 1.36 \times 10^3\ T_f - 2.72 \times 10^4$$
$$1.46 \times 10^3\ T_f = 3.68 \times 10^4$$
$$T_f = 25.2°\text{C}$$